CLAIMS

What is claimed is:

1.   A method for aligning a first image and a second image, comprising:

(1) selecting a first pixel in the first image and a second pixel in the second image that overlap when the first image and the second image are aligned with a camera motion;

(2) if the first and the second pixels are edge pixels, incrementing a correlation value between the first image and the second image for the camera motion;

(3) if only one of the first and the second pixels is an edge pixel, decrementing the correlation value between the first image and the second image for the camera motion;

(4) repeating steps (1) to (3) for other overlapping pixels in the first image and the second image to determine the correlation value between the first image and the second image for the camera motion.

2.   The method of claim 1, wherein the camera motion includes a translation and a rotation.

3.   The method of claim 1, further comprising determining if the first and the second pixels are edge pixels, said determining comprising:

applying an edge detection filter to the first pixel to generate a first result;

comparing the first result to a first threshold, wherein the first pixel is an edge pixel when the first result is greater than the first threshold;

applying the edge detection filter to the second pixel to generate a second result; and

comparing the second result to a second threshold, wherein the second
pixel is an edge pixel when the second result is greater than the second
threshold.

4.   The method of claim 3, wherein the edge detection filter is a Sobel filter defined as:

$$g_x(x,y) = I(x+1,y-1) + 2I(x+1,y) + I(x+1,y+1) - I(x-1,y-1) - 2I(x-1,y) - I(x-1,y+1);$$
$$g_y(x,y) = I(x-1,y+1) + 2I(x,y+1) + I(x+1,y+1) - I(x-1,y-1) - 2I(x,y-1) - I(x+1,y-1);$$
$$G(x,y) = |g_x(x,y)| + |g_y(x,y)|;$$

wherein g_x is a Sobel gradient in the x-direction, g_y is a Sobel gradient in the y-direction, G is a
Sobel gradient in the x-direction and the y-direction, and I is a pixel value.

5.   The method of claim 1, wherein said incrementing a correlation value between the first
image and the second image for the camera motion comprises:

determining an edge orientation matching value representing how closely the first
pixel and the second pixel match in edge orientation; and

incrementing the numerator of the correlation value by the edge orientation
matching value.

6.   The method of claim 5, wherein said determining an edge orientation matching value
comprises:

applying a second order differential edge detection filter to the first pixel in the
first image to generate a first result;

applying the second order differential edge detection filter to the second pixel in
the second image to generate a second result;

calculating the edge orientation matching value as follows:

$$\frac{2L(p)L'(p')}{L^2(p) + L'^2(p')},$$

wherein L(P) is the first result and L'(p') is the second result.

7.   The method of claim 6, wherein the second order differential edge detection filter is a Laplace filter defined as:

$$L(x,y) = I(x,y) - \frac{1}{9}\sum_{i=-1}^{1}\sum_{j=-1}^{1}I(x+i, y+j),$$

wherein L is a Laplace gradient and I is a pixel value.

8.   The method of claim 1, wherein said decrementing the correlation value between the first image and the second image for the camera motion comprises decrementing the numerator of the correlation value and incrementing the denominator of the correlation value.

9.   The method of claim 1, further comprising:

(5) repeating steps (1) to (4) for other camera motions to generate correlation values for the other camera motions; and

(6) selecting a group of the camera motions generating large correlation values.

10.   The method of claim 9, wherein said selecting a group of the camera motions generating high correlation values comprises:

selecting each camera motion that has a correlation value (1) greater than or equal to its neighboring camera motions, and (2) greater than at least one of the neighboring camera motions.

11.   The method of claim 9, further comprising:

(7) determining for each member of the group of the camera motions a matched edge count;

(8) selecting one camera motion having the largest matched edge count from the group of the camera motions; and

(9) aligning the first image and the second image according to the selected camera motion.

12. The method of claim 11, wherein a matched edge count is defined as:

$$MEC = \sum_{p \in W} k(L(p), L'(p'), G(p), G'(p'))$$

$$k(L(p), L'(p'), G(p), G'(p')) = \begin{cases} 1 & \text{,if } G(p) > T \text{ AND } G'(p') > T' \text{ AND } \dfrac{2L(p)L'(p')}{L^2(p) + L'^2(p')} \geq \dfrac{1}{3} \\ 0 & \text{,else} \end{cases}$$

wherein MEC is the matched edge count, W is an overlapping region between the first image and the second image under the camera motion; p and p' are overlapping points in the overlapping region from the first image and the second image, respectively; L(p) is a first Laplace gradient of the first point; L'(p') is a second Laplace gradient of the second point; G(p) is a first Sobel gradient of the first point; G'(p') is a second Sobel gradient of the second point; T is a first Sobel threshold for detecting an edge in the first image; and T' is a second Sobel threshold for detecting an edge in the second image.

13. A method for aligning a first image and a second image, comprising:

(1) generating a plurality of correlation values for a camera motion, the camera motion comprising a translation and a range of rotation after the translation, a correlation value being defined as:

$$Corr = \frac{\sum_{p \in W} f(L(p), L'(p'), G(p), G'(p'))}{\sum_{p \in W} h(G(p), G'(p'))}$$

$$f(L(p), L'(p'), G(p), G'(p')) = \begin{cases} \dfrac{2L(p)L'(p')}{L^2(p) + L'^2(p')} & \text{,if } G(p) > T \text{ AND } G'(p') > T' \\[4pt] -\dfrac{1}{2} & \text{,if } G(p) > T \text{ OR } G'(p') > T' \\[4pt] 0, & else \end{cases}$$

$$h(G(p), G'(p')) = \begin{cases} 1 & \text{,if } G(p) > T \text{ OR } G'(p') > T' \\ 0, & else \end{cases}$$

wherein Corr is the correlation value; W is an overlapping region between the first image and the second image under the camera motion; p and p' are overlapping points in the overlapping region from the first image and the second image, respectively; L(p) is a first Laplace gradient of the first point; L'(p') is a second Laplace gradient of the second point; G(p) is a first Sobel gradient of the first point; G'(p') is a second Sobel gradient of the second point; T is a first Sobel threshold for detecting an edge in the first image; and T' is a second Sobel threshold for detecting an edge in the second image.

(2) selecting a maximum correlation value from the plurality of correlation values for the camera motion;

(3) repeating (1) and (2) for other camera motions to generate maximum correlation values for the other camera motions;

(4) generating a map comprising the maximum correlation values at coordinates of their translation vectors; and

(5) selecting a group of the maximum correlation values that form peaks in the map.

14.   The method of claim 13, further comprising using a Laplace filter to generate the first and the second Laplace gradients, the Laplace filter comprising:

$$L(x,y) = I(x,y) - \frac{1}{9}\sum_{i=-1}^{1}\sum_{j=-1}^{1} I(x+i, y+j),$$

wherein L is a Laplace gradient and I is a pixel value.

15.   The method of claim 14, further comprising using a Sobel filter to genereate the first and the second Sobel gradients, the Sobel filter comprising:

$$g_x(x,y) = I(x+1,y-1) + 2I(x+1,y) + I(x+1,y+1) - I(x-1,y-1) - 2I(x-1,y) - I(x-1,y+1);$$
$$g_y(x,y) = I(x-1,y+1) + 2I(x,y+1) + I(x+1,y+1) - I(x-1,y-1) - 2I(x,y-1) - I(x+1,y-1);$$
$$G(x,y) = |g_x(x,y)| + |g_y(x,y)|;$$

wherein g_x is a Sobel gradient in the x-direction, g_y is a Sobel gradient in the y-direction, and G is a Sobel gradient in the x-direction and the y-direction.

16.   The method of claim 15, wherein each of the peaks in the map comprises a point having a maximum correlation value (1) greater than or equal to all of its neighboring points, and (2) greater than at least one of the neighbor points.

17.   The method of claim 16, further comprising:

(6) selecting from the group one camera motion having the largest matched edge count, wherein a matched edge count is defined as:

$$MEC = \sum_{p \in W} k(L(p), L'(p'), G(p), G'(p'))$$

$$k(L(p), L'(p'), G(p), G'(p')) = \begin{cases} 1 & , \text{if } G(p) > T \text{ AND } G'(p') > T' \text{ AND} \dfrac{2L(p)L'(p')}{L^2(p) + L'^2(p')} \geq \dfrac{1}{3} \\ 0 & , else \end{cases}$$

wherein MEC is the matched edge count.

18.   The method of claim 17, further comprising:

(7) aligning the first image and the second image according to the selected camera motion.